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14. ABSTRACT

The work performed under Grant #F49620-03-1-0206 included the analysis of a unique database on the hard flutter of a Flexible Semispan Model of a High Speed Civil Transport model. The experiments were performed in the Langley Transonic Dynamic Tunnel. These experiments are unique in terms of the model scaling and characteristics, the range of Mach number and dynamic pressure and the observed phenomena. To date, the analysis of the data performed with the support of AFOSR yielded two journal articles and two conference papers. The abstracts of these articles and their reference numbers are listed in Appendix A. Moreover, a new computer code has been developed to identify cubic nonlinearities of any system.

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VALIDATION TOOLS OF NONLINEARITIES ASSOCIATED WITH AEROELASTIC PHENOMENA

Final Report

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VALIDATION TOOLS OF NONLINEARITIES ASSOCIATED WITH AEROELASTIC PHENOMENA

Grant # F49620-03-1-0206
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Background and Objective:

Current and future designs of aircraft require light-weight structures that may be very flexible. This requirement has its own penalties in terms of aeroelastic constraints. The prediction, modeling, testing and analysis of aeroelastic phenomena are extremely difficult. With the advances made in computing power and technology, there is a need to develop validation tools that can be applied to numerical and experimental data and whereby physical phenomena related to nonlinear aeroelasticity can be quantified. These tools are essential if computational aeroelasticity is to be used for prediction of flutter, LCO or divergence boundaries and for the separation of benign and catastrophic aeroelastic instabilities.

The objective of the work funded under Grant # F49620-03-1-0206 is to develop analysis tools that can identify and quantify nonlinear physical processes that arise from (1) the aerodynamic loading in different flow regimes, (2) flexible components that may undergo large deformations and (3) the interaction of the structure with the surrounding flow field. Because tools based on linear analysis could not be used to identify nonlinear aeroelastic phenomena, the effort stressed the use of tools capable of identification of nonlinearities, namely, the bispectrum and trispectrum.

Accomplishments:

The work performed under Grant # F49620-03-1-0206 included the analysis of a unique database on the hard flutter of a Flexible Semispan Model of a High Speed Civil Transport model. The experiments were performed in the Langley Transonic Dynamic Tunnel. These experiments are unique in terms of the model scaling and characteristics, the range of Mach number and dynamic pressure and the observed phenomena. To date, the analysis of the data performed with the support of AFOSR yielded two journal articles and two conference papers. The abstracts of these articles and their reference numbers are listed in Appendix A. Moreover, a new computer code has been developed to identify cubic nonlinearities of any system.

Technology Transfer:

The techniques and new scientific knowledge developed in this effort are currently used by Dr. Walter Silva of NASA LaRC to analyze F/A-18 flutter and LCO test data obtained from the Royal Australian Air Force (RAAF).

The Principal Investigator plans to contact Drs. Denegri and Beran at AFRL to possibly establish cooperation on the application of the developed validation and analysis procedures to flight test data and numerical simulations.

Discussions with AFRL personnel have been initiated and seminars at AFRL (WP) and specialty workshops have been presented on the possibility of applying the same analysis techniques developed with this effort for damage prognosis of materials.

Appendix A:

"Nonlinear Flutter Aspects of the Flexible High-Speed Civil Transport Semispan Model" Journal of Aircraft, 1 September 2004, vol. 41, no. 5, pp. 1202-1208(7) The nonlinear aspects that lead to the flutter of the flexible semispan model of a high-speed civil transport wing configuration are analyzed. A hierarchy of spectral moments was used to determine the characteristics of the aerodynamic loading and structural strains and motions. The results show that the frequency of the bending motion of the wing varied significantly as the Mach number was increased between 0.90 and 0.97. Examination of the pressure coefficients in terms of mean value and fluctuations showed that the flow characteristics over the wing changed significantly around a Mach number of 0.97. A strong shock was identified near the trailing edge. Nonlinear analysis of the pressure fluctuations, under these conditions, showed nonlinear coupling involving low-frequency components at pressure locations where the mean value was at a local minimum. This shows that the aerodynamic forces acting on the model had nonlinearly coupled frequency components. The presented results show how nonlinear analysis tools can be used to identify nonlinear aspects of the flutter phenomenon, which are needed in the validation of nonlinear computational methodologies.

"Time/Frequency Analysis of the Flutter of the Flexible HSCT Semispan Model" Journal of Aircraft (accepted), also presented as AIAA paper # 2004-1856 Time/frequency analysis of fluctuations measured by pressure taps and strain gages in the experimental studies of the Flexible Semispan Model of High Speed Civil Transport wing configuration is performed. The interest is in determining the coupling between the aerodynamic loadings and structural motions that lead to the hard flutter conditions and loss of the model. The results show that, away from the hard flutter point, the aerodynamic loadings at all pressure taps near the wing tip and the structural motions contained the same frequency components. On the other hand, in the flow conditions leading to the hard flutter, the frequency content of the pressure fluctuations near the leading and trailing edges varied significantly. This lead to contribution over two frequency ranges to the structural motions. The ratio of these ranges was near 2 to 1 which suggests the possibility of nonlinear structural coupling.

Structural Nonlinearities of the Flexible HSCT Semispan Model AIAA paper # 2005-1858 The nonlinear dynamics observed in the analysis presented in this work yield some very important conclusions. First, fluid-flow structures such as shock formation or flow separation that have frequency components with near half or double the natural frequencies could contribute to an amplified response of the wing via structural nonlinearities. Second, combination resonance might play an important role as well. The wide range of linear response region, between 11 and 14 Hz, raises the possibility that a wider range of flow structures could contribute to nonlinear excitations. Finally, the observed nonlinearities could be exploited to perform system identification and obtain the coefficients of a reduced-order model for the structural response of the FSM wing model.